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Outdoor Comfort in Public Spaces, a Critical Review

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ABSTRACT

A comfortable outdoor microclimate encourages outdoor physical activity and enhances user health and wellbeing. This study reviews the literature on outdoor comfort. The literature review focuses on the following four critical aspects of outdoor comfort: 1) the types of comfort that play significant roles in human outdoor activities, 2) the parameters (and/or values) used as indicators to evaluate outdoor comfort, 3) the critical urban design features that improve outdoor comfort, and 4) urban design interventions (guidelines) to enhance outdoor comfort in public spaces. This paper provides a comprehensive understanding of the physical, psychological, and design factors that influence the outdoor comfort of public spaces. It concludes with a discussion of future research directions in outdoor comfort and public space design.

1. INTRODUCTION

Outdoor comfort has become the primary goal to assess the quality of public space design. However, controversially, there is no universally accepted standard for outdoor comfort. Existing studies on outdoor comfort have focused on the definition of thermal comfort and its influencing factors, including climatic and physical factors (Elnabawi & Hamza, 2020; Lai, 2017; Mackey et al., 2017; Rakha et al., 2017; Shooshtarian et al., 2020). Except for the general concept of thermal comfort, there is no strict definition of outdoor thermal comfort. Thermal comfort is generally defined for indoor conditions as a psychological state that expresses satisfaction with the thermal environment and is assessed through subjective evaluations (ASHRAE, 2020). It is usually expressed using a thermal comfort index determined by measuring the heat balance of the human body and the surrounding environment. The thermal comfort indices were developed in the specific steady-state controlled environment. They are not suitable for outdoor environments, which are dynamic with constantly changing temperature, wind speed, radiation, lighting, landscape, and other environmental factors. The dynamic outdoor environments pose significant challenges to maintaining the homeostasis of the microclimate associated with the human body, so the thermal equilibrium between the human body and the environment is in a state of change that is difficult to stabilize. In addition to a physiological indicator, the thermal comfort index is a psychological state that is influenced by environmental changes. Outdoor thermal comfort studies are not a substitute for studies of real-world outdoor comfort (Peng et al., 2019a). The assessment of outdoor comfort is complex. It should consider the psychological aspects of the user's interaction with the design of the outdoor public space (e.g., the atmosphere, climate, noise, and lighting) and the socio-demographic background of the user (gender, age, education, height, and income) in addition to the physiological experience (Chen & Ng, 2012; Mackey et al., 2017; Reiter, 2004; Reiter & De Herde, 2003; Shooshtarian et al., 2020). Assessing outdoor comfort involves

complex evaluation parameters based on outdoor thermal comfort and some psychological/human factors (MH Elnabawi, N Hamza, 2020; Pardeep Kumar & Amit Sharma, 2020).

As of March 2022, a search for studies on outdoor comfort and human behavior in public spaces by using sciencedirect and google scholar reveals that no more than ten research teams have investigated the topic. Most of these have studied outdoor thermal comfort by examining people's comfort and behavior in public spaces. The earliest research on outdoor thermal comfort was conducted by Reiter & Herde (2003) two decades ago. They used both quantitative and qualitative analyses to study outdoor comfort. Quantitative research focuses on physiological thermal comfort, including climatic factors such as air temperature, wind speed, radiation, and relative humidity, and human factors such as activity and clothing (Elnabawi & Hamza, 2020; Lai, 2017; Mackey et al., 2017; Rakha et al., 2017; Shooshtarian et al., 2020). The qualitative analysis focuses on design aspects such as the atmosphere of the outdoor environment, whether the climate is diverse, whether people believe they can potentially control the environment, and the natural attributes of the site. Except for Reiter & Herde (2003), studies related to outdoor comfort and human behavior in space are all from the past five years and examine either psychological or design factors that affect human outdoor comfort. Therefore, research on outdoor comfort and human behavior in public spaces must be strengthened and clarified. It is also necessary to review and summarize the current state of the art. Defining which comfort levels and factors influence outdoor thermal comfort and how outdoor comfort can help future public space design assessments and promote sustainable urban development.

2. METHODOLOGY

A search using the keywords of public space, human behavior, outdoor thermal comfort, and outdoor comfort identified forty-four articles from 2001 to 2021, with most studies published in the past five years (figure 1). Research fields covered are outdoor thermal comfort, outdoor comfort, human behavior, urban design factors, and psychological factors (figure 2). The research methods include case study calibration, case study analysis and comparison, onsite observation and analysis, validation experiments, comfort mapping, critical review, creating new assessment levels/frameworks, online surveys, theoretical analysis, or a combination of these methods. As figure 3 shows, nearly half of the researchers use simulation and comparison methods to do the research. 20% of studies used observation, field measurement, questionnaire, and analysis methods. The simulation and field observation methods count for 48% of total research (of the total). Other methods are data analysis (23% of the total), critical review (11% of the total), and mapping (5% of the total). As shown in figure 4, ten out of forty-four studies (22% of the total) do not explicitly state the research's season. Twenty-eight studies (63% of the total) were conducted in the summer. Sixteen studies (36% of the total) were conducted in winter. Eleven studies (25%) were conducted in spring, and five studies were conducted in the fall, 11%. Nineteen studies were conducted in more than one season, 43% of the total.

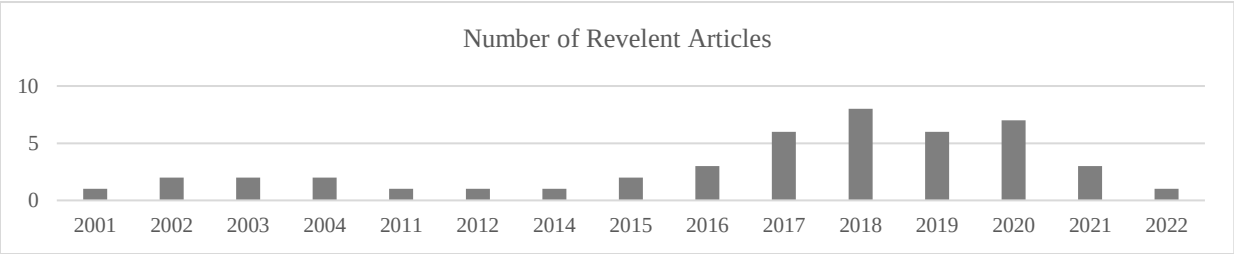

Figure 1: Number of articles related to public space, human behavior, outdoor thermal comfort, and outdoor comfort

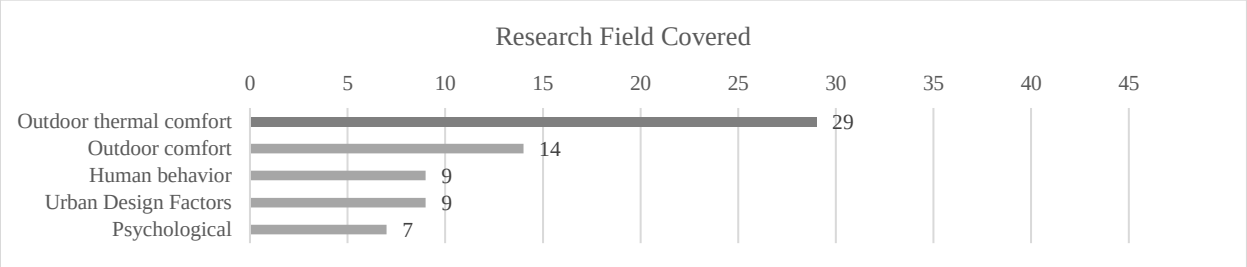

Figure 2: Research areas of the reviewed papers

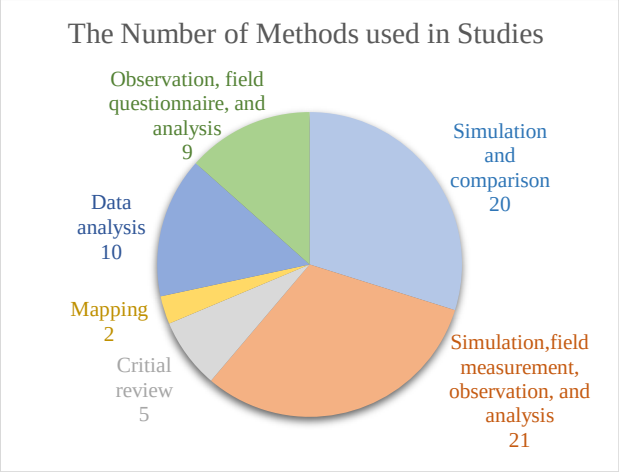

Figure 3: Number of methods used in 44 studies

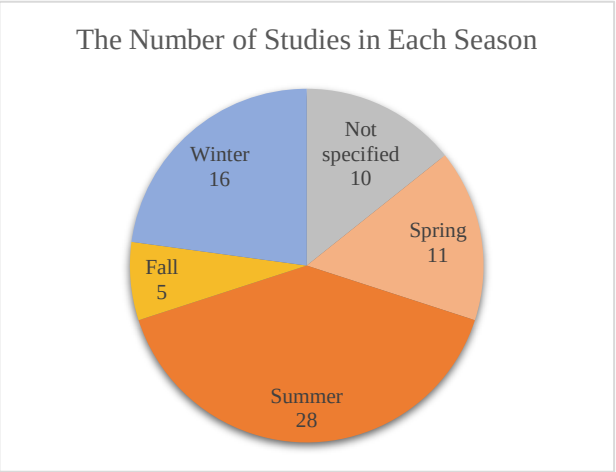

Figure 4: Number of studies in each season

Most studies have three steps for outdoor comfort in public spaces: selecting the site and research interest, simulation, and collecting data on outdoor comfort or thermal comfort. Most of the studies used the following methods: simulation and comparison, field measurements, observations, interviews, questionnaires, mapping, data analysis, and structural equation modeling. Some studies directly use thermal comfort index without valibarting or adjusting. For example, Sodoudi et al. (2018) used thermal comfort index and focused on simulating and analyzing several different outdoor design scenarios. Farajzadeh & Matzarakis (2012) used thermal comfort index to find the best months for tourism in Ourmieh Lake, Iran. Tumini (2016) used microliacte simulate software and thermal comfort index to test the different microclimate condition and thermal comfort perception for best urban renovation strategies. Naboni et al.(2018) only compared and analyzed the difficulty of using different climate simulation software for designers, but their study do not involve verification. They did not focus on outdoor comfort assessment or thermal comfort indicators. There is no universally accepted detailed index representing outdoor thermal comfort. Most of the case studies directly use some existing thermal comfort indices such as predicted mean vote (PMV), percentage dissatisfaction index (PPD), physiologically equivalent temperature (PET), standard effective temperature (SET), and universal thermal climate index (UTCI) to evaluate outdoor thermal comfort or outdoor comfort (Du et al., 2020; Fang et al., 2017; Lai, 2017; Salata et al., 2016).

Other studies have validated the calculated thermal comfort against empirical studies, often producing inconsistent results. Therefore, some scholars focused on improving outdoor comfort and outdoor thermal comfort threshold (Du et al., 2020; Fang et al., 2017; Salata et al., 2016). Some studies used questionnaires and field measurements to adjust the optimal thermal comfort interval calculated using a thermal comfort index (Farshid Aram, 2019; Sharifi et al., 2016; Ehsan Sharifi & John Boland, 2018; Jiawei Yao et al., 2018). Some studies directly measured the physical factors in the field and observed the environmental factors that affect human activities outdoors. Some studies include questionnaires for calibrating the outdoor thermal comfort index. Researchers then performed data analysis to determine the outdoor comfort zone and the factors that affect human outdoor comfort. However, the optimal thermal comfort interval for human outdoor activities is often difficult to predict. Some authors argued that the problem arises because rational thermal comfort metrics alone are insufficient to reflect the full range of human thermal comfort (Nikolopoulou & Steemers, 2003; Peng et al., 2021). After all, the underlying assumption of rational indicators is that thermal equilibrium between the human body and its surroundings is equivalent to thermal comfort (Peng et al., 2021). Thermal equilibrium reflects the physiological perception of an objective world as hot or cold.

On the other hand, thermal comfort is a sensation, an emotional experience relative to expectations (Ehsan Sharifi & John Boland, 2018, 2020; ASHRAE, 2020; JLM Hensen, 1990; Peng You et al., 2019). The difference between thermal equilibrium and thermal comfort was confirmed by experimental studies long ago (AP Gagge, 1969; Peng You et al., 2019). Research that goes beyond the purely physiological outdoor thermal comfort threshold should consider the influence of human emotions, expectations, and perceptions to fall into the broader category of outdoor comfort studies (Peng et al., 2019a, 2019b, 2020; Reiter, 2004; Reiter & De Herde, 2003).

3. RESULTS

Thermal Comfort Factor

According to figure 2, twenty-nine of forty-four studies on thermal comfort, accounting for 66%, reveals that thermal comfort is a significant factor in outdoor comfort and influences human activity in public spaces (table 1). Sharifi et al.'s (2016, 2020) research studied the relationship between outdoor thermal comfort and human behavior. They have conducted studies in several Australian cities such as Adelaide, Sydney, and Melbourne using case studies, field measurements, observations, and online questionnaires. They classified human behavior in public spaces as necessary, optional, and social. According to the changes of people engaged in the three behaviors in public areas at different air temperatures in summer, they derived the degree of influence of thermal comfort on human behavior and estimated the outdoor thermal neutrality threshold and thermal adaptation limit of public spaces and using it to modify the outdoor thermal comfort index. The results showed that thermal comfort is the dominant factor in outdoor comfort. Nikolopoulou (2001) concluded that the thermal environment is the primary factor affecting human use of these spaces by observing people in squares, streets, and gardens in Cambridge, UK, during four seasons. Farajzadeh and Matzarakis (2012) also considered thermal comfort an essential factor influencing travel. They conducted a simulation study in Ourmieh, Iran, using outdoor thermal comfort simulation software to explore this possibility. They concluded that June through September is the most comfortable time for tourism, sports, and recreational activities in Ourmieh.

Table 1: Thermal comfort factors

Author-year	Sub-field	Thermal Comfort Factors	Type	Season	Methods
Sharifi et al. (2016)	Outdoor thermal comfort & human behavior & outdoor comfort	Outdoor thermal comfort measurement (humidty, wind, sunshine), thermal environment, heat stress	Online survey	Not specified	Data analysis, survey
Ehsan Sharifi & John Boland, (2020)	Outdoor thermal comfort & human behavior	Outdoor thermal comfort measurement, thermal comfort index, thermal adaptation	Case study and field observation	Summer	Observation, analysis, passive activity observation
Marialena Nikolopoulou (2001)	Outdoor comfort, outdoor thermal comfort, Urban design, Human Parameter	Comfort condition outdoor, thermal comfort measurement, human parameter	Case study analysis	Spring, summer, winter	Data analysis
Farajzadeh et al. (2011)	Outdoor thermal comfort	Outdoor thermal comfort measurement, thermal comfort index	Case study simulation	Summer	Simulation and comparison
Shooshtarian et al. (2020)	Outdoor thermal comfort & human behavior	Thermal comfort assessment, human behavior, thermal comfort index	Summarize and analysis review (critical)	Not specified	Literature review
Liang Chen, Edward Ng (2012)	Human behavioral aspects of outdoor thermal comfort	Thermal comfort assessment, human behavior, thermal comfort index, assessment level (physical, psychological, social and behavioral)	Critical review	Not specified	Create a new outdoor thermal comfort assessment, survey, observation
MH Elnabawi and N Hamza. (2020)	Outdoor thermal comfort & human behavior	Thermal comfort assessment, human behavior, thermal comfort index	Critial review	Not specified	Create new assessment level, objective based and subjective assessment

One individual study and two critical literature reviews examining thermal comfort and human behavior have concluded that thermal comfort and human activity in public spaces are highly correlated. Shooshtarian (2017)

reviewed Australian studies related to thermal comfort assessment in a literature review. Most of these studies used a combination of subjective thermal comfort assessment and field observations. They employed different thermal comfort indicators to determine the thermal neutrality of the study site and the choice of outdoor activities under other meteorological conditions in summer. Chen and Ng (2012) created an innovative framework for evaluating outdoor thermal comfort based on aspects of human performance after reviewing research in the past decade on outdoor thermal comfort and outdoor activities. This framework is divided into four levels: physical, physiological, psychological, and social/behavioral. The first two levels are obtained by measuring, simulating, and monitoring objective influences related to thermal comforts, such as sun, temperature, wind, and energy balance. The latter two levels are obtained by surveying, interviewing, and observing the main factors related to human behavior, such as expectations, past experiences, and preferences. A decade later, Elnabawi and Hamza (2020) refined Chen and Edward's outdoor thermal comfort evaluation framework to create a more comprehensive framework for designers and planners. The framework requires that the outdoor thermal comfort index be corrected by onsite measurement and thermal sensation questionnaires before the index is used. The thermal sensation is linked to the usage pattern of space; for example, the perception of outdoor thermal comfort is assessed in behavior.

Environmental factors that influence thermal comfort

Table 2: Environmental factors that influence thermal comfort

Author-year	Sub-field	Environmental Factor	Type	Season	Methods
Christopher Mackey (2017)	Universal thermal climate index (UTCI) Mapping, microclimate maps	Wind speed, sun, surface temperature, heat island	Case study calibration	Not specified	Simulation and comparison
Rakha et al. (2017)	Thermal comfort mapping	Mean radiant temperature	Case study simulation	Spring, summer, and winter	Simulation, MRT mapping
Pamela Smith, Cristián Henríquez (2018)	Outdoor comfort & recommendations for analysis and design; urban design	Morphoclimatic parameters of selected public spaces: (Land) surfaces, sky view factor, H/W, shadow, and radiation; land use, the proportion of built space, thermic quality of materials, orientation and slope of the surface, vegetal cover, ground humidity	Case study simulation & experiment	summer	Field measurement, observation, analysis
Katzschner et al. (2003)	Bioclimatic comfort mapping	Morphology (surface, tree, vegetation), meteorology (solar radiation, wind speed), sky view factor	Comfort mapping	Not specified	Analysis & mapping
Jason D. Wark et al. (2020)	Thermal comfort in the zoo	Material, shade	Case study analysis	Spring, summer, fall	Observation and analysis

Environmental stimuli influence human thermal comfort. Therefore, researchers have also studied environmental factors (table 2). For example, Sharifi and Boland (2020) categorized human activity outdoors as necessary, optional, and social and examined it through passive activity observation in Australia. Mackey (2017) argues that the sun brings heat exchange, and wind (rather than surface temperature or heat island) is the leading cause of the inability to predict outdoor thermal comfort accurately. Rakha et al. (2017) argued that MRT, a physical quantity representing the radiation around the human body, is a key factor influencing outdoor thermal comfort assessment. They proposed a simulation method to improve MRT measurements by conducting experiments in an outdoor space in Syracuse, NY, USA. In Chillán City, Chile, Smith, and Henríquez (2018) considered relative humidity a key factor influencing outdoor thermal comfort. They found that the most uncomfortable users occurred along the Parque Estero Las Toscas

River, where the air was unexpectedly dry. Katzschner et al. (2003) argued that design, morphology (geometry of buildings, surfaces, trees/vegetation), time, and meteorology (solar radiation and wind speed) are the fundamental structures of thermal comfort zoning mapping. Wark et al. (2020) found that habitat material and shading are the main factors influencing outdoor thermal comfort by studying zoo animals' activities. In the literature mentioned above, the parameters and values used to evaluate the thermal comfort aspects of outdoor comfort are air temperature, mean radiation temperature, wind, radiation/sun/solar radiation/shading, relative humidity, activity, clothing, morphology, and time.

Table 3: Psychological factors that influence thermal comfort

Author-year	**Sub-field**	**Psychological factors**	**Type**	**Season**	**Methods**
Tian et al. (2022）	Thermal perception (comfort; design aspect)	Thermal sensation acceptability, factors influencing thermal perception (physical, individual, social, psychological)	Field experiment and analysis	Spring, summer, and winter	Observations, simulation, questionnaire, analysis
Elham Zabetiana and Reza Kheyroddin (2019)	Thermal adaptation	Feeling and perception of it (psychological), thermal comfort felt in the two selected urban spaces, seven levels of sense of place	Case study experiment	Summer and winter / cold and warm	Spatial analysis, questionnaire, simulation and comparison
Ehsan Sharifi & John Boland (2018)	Outdoor thermal comfort & thermal adaptation & human behavior & outdoor comfort	Local and seasonal climate expectations, comfort perceptions, demographic specifications, activity choices, and socio-cultural norms	Field observation and analysis	Winter	Observations, questionnaire, and analysis
Peng et al. (2019)	Outdoor comfort	Need satisfaction of outdoor activity (expectation of thermal and wind condition), acceptability of outdoor activity (emotional status, preference of wind and sunlight)	Field measurement and analysis	Spring	Survey and analysis
Peng et al., (2019)	Outdoor comfort	Environment sensation, urban setting perception, expectation, preference, emotion	Case study simulation, experiment, and analysis	winter/ spring	Data analysis (qualitative); simulation and comparison, field measurement
Peng et al., (2021)	Outdoor comfort	Acceptability/need of outdoor activity,	Case study simulation, experiment and analysis	All four seasons	Case study, data analysis (qualitative), survey, simulation and comparison, field measurement

Psychological Factor

In recent years, researchers have slowly begun to highlight the role of psychological factors in evaluating outdoor comfort (table 3). Tian et al. (2022) studied the thermal comfort of open spaces in Xi'an, China. Using meteorological measurements and questionnaires, they concluded that psychological and individual factors and physical factors are the main determinants of the comfort of outdoor spaces in spring and summer. Physical and social factors are the primary influences on human activities in outdoor spaces in winter. The psychological factors in this study include the length of residence, time of exposure, frequency of visits, overall satisfaction, differences in climatic region, and the purpose of visit. Zabetiana and Kheyroddin (2019) argued that the different sense of place in urban spaces is directly related to thermal comfort, i.e., the psychological states influenced by contextual variables and thermal comfort are correlated. A study of two German squares in winter and summer found that the respondents' mood and sense of place (including the diversity of the venue's activities and the attractiveness) correlated with thermal comfort (Zabetiana and Kheyroddin, 2019). However, age, gender, and clothing had low correlations with thermal comfort.
From his survey of several Australian cities, Sharifi and Boland (2018) concluded that outdoor climate expectations, comfort perceptions, and socio-cultural norms are psychologically biased factors that impact outdoor comfort. Peng et al. (2019a, 2019b, 2021) argued that current thermal comfort research is not an adequate substitute for comfort research. They sought to create a new modeling framework to extend outdoor comfort assessment by adding the following human factors: socio-demographic, psychological, and behavior. The socio-demographic characteristics are age, sex, education, and body mass index. The psychological factors include environmental sensation, urban setting perception, and expectation. The parameters and values used as the indicators to evaluate the psychological aspects of outdoor comfort are a sense of place/environment sensation/urban setting perception, length of residence, frequency of visits, time of exposure, the respondent's emotion, overall satisfaction, the purpose of the visit, differences of climatic region, expectation, preference, diversity of site activities, and attractiveness of the activities.

Urban Design Factor

In addition to thermal comfort and psychological factors, public space design also influences outdoor comfort (table 4). The impact of the design of urban or public spaces on human comfort outdoors can be broadly divided into two categories: the effects of the background design of public spaces and the impact of the ambient design of public spaces. For example, most studies emphasized the materials and layouts within public areas that can affect thermal comfort. Through onsite measurements and simulation analysis of the campus of Changwon National University in South Korea, Dain et al. (2015) concluded that pavements of different materials have different impacts on thermal comfort. Perini et al. (2017) used two simulation programs to simulate urban form and vegetation to determine their importance for thermal comfort. Through field measurements and simulations, Aram (2019) concluded that Large-Scale Urban Parks positively affect the thermal comfort of the surrounding environment. Nouri et al. (2018) presented four Measure Review Frameworks to refine the analysis of greenery, shading, vertical façade surface materials, and fountain sizes to determine how different combinations mitigate thermal comfort in public spaces. Smith and Henríquez (2018) observed and measured five public spaces in central and southern Chile, South America. They evaluated the effect of impervious (land) surfaces, sky view factor, H/W, land use, the proportion of built space, the thermic qualities of materials, vegetal cover, orientation, and slope of the surface on human quality of life. In a study on three typical weather days in Gulou Square, Nanjing, China, Xu et al. (2019) found that outdoor thermal perception, sunshine perception, and visual perception have an essential impact on human quality of life and human activities in public spaces.

On the other hand, the atmosphere of public space also impacts human activities. Reiter & Herde (2003, 2004) have suggested the importance of various qualitative factors in evaluating outdoor comfort, including the following: "identification of an atmosphere, relation with the context, continuity of the environmental conditions, diversity of the environmental conditions, variability of the environmental conditions, perception of potential control, the capacity of adaptation, naturality of the place, meaning of the place, globality of the comfort feeling." In research on German squares, Zabetiana and Kheyroddin (2019) proposed a seven-level sense of place emphasizing the significance of the ambiance of public places. The literature mentioned above shows that researchers use the following design-related parameters and values as indicators to evaluate outdoor comfort: greenery/tree/vegetation/park/vegetal cover, different materials of artificial pavement/land surface, thermic qualities of materials, the surface materials of vertical façade, water, shading/sunshine perception/sky view factor, height-to-width ratio, the proportion of built space, orientation, the slope of the surface, urban form, land use, urban atmosphere (as mentioned by Reiter & Herde, (2003)), and sense of place (as mentioned by Zabetiana and Kheyroddin (2019)).

Table 4: Urban design factors that influence thermal comfort

Author-year	Sub-field	Design factors	Type	Season	Methods
Dain et al. (2015)	Outdoor thermal comfort	Paving material, tree, building type	Validation experiment	Summer	Simulation and comparison
Perini et al. (2017)	Outdoor comfort, built environment	Urban form, vegetation and canyon proportion affecting urban microclimate	Case study analysis and comparison	Summer	Experiment, simulation and field, measurement comparison
Farshid Aram (2019)	Outdoor thermal comfort	Size of the urban park, distance from the park	Case study experiment	Summer	Data analysis, simulation, survey
Nouri et al. (2018)	Outdoor thermal comfort & Public Place Design	The different techniques, and measures are reviewed and framed into four measure review frameworks (green, sun, surface, water)	Critical review	Summer	Simulation, and comparison
Xu et al. (2019)	Outdoor comfort & human behavior	Location of public facilities (such as seats, pergola, entrances and exits) and extension of vision	Case study simulation and experiment	Spring, summer, winter	Observation, simulation, comparison and data analysis

Many design factors influence outdoor human comfort. However, similar factors can be grouped into categories to reduce the number of indicators. For example, land surface and vegetation cover are artificial pavement but in different materials; these indicators can be summarized as natural properties. The urban design features that can enhance outdoor comfort and attract more people can be summarized into the following categories: natural properties, visual effect, urban form, function, variety, control, variability, activity, and the sense of place. More specific interventions include greening rate, sunlight, shading, sky view factor, fountains, pools, the thermal quality of different artificial pavement and façade materials, type and number of events, movable components, and the possibility of versatile use (localization change).

4. CONCLUSIONS

This paper reviews the research on the human impact of outdoor comfort in public spaces over the past two decades through a literature review. It clarified the differences between outdoor and thermal comfort and categorized the numerous factors that may affect outdoor comfort. The most important contribution of this literature review paper is the elucidation of three important categories of factors that affect human outdoor comfort: physical, psychological, and urban design factors. This article distinguishes outdoor comfort and outdoor thermal comfort research at the present stage. The concept of outdoor comfort responds to the narrowness of the more prevalent vision of outdoor thermal comfort.

As research on outdoor comfort reveals, thermal comfort remains a major factor influencing human outdoor activity, but psychological and design factors also influence human perceptions of the comfort of the surrounding environment. Psychological changes follow the influence of external conditions. In particular, the environment's design affects the perception of outdoor comfort through sight and sensation. Good design provides a variety of microclimatic conditions for the site. These microclimatic conditions are linked to the site's thermal comfort and psychological aspects, influencing the evaluation of outdoor comfort. Therefore, future outdoor comfort research in public spaces should focus on design scenarios. Improving outdoor comfort through scene design will attract more people outdoors while providing them better thermal comfort, ultimately increasing human outdoor activities.

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